

Observation of Velocity Overshoot in Silicon Inversion Layers

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Abstract—Employing a novel test structure, electron velocity overshoot in silicon inversion layers is observed at room temperature. For channel lengths longer than 0.3 μm , the velocity / field relation follows the well-known behavior with no channel length dependence. The first indication of velocity overshoot is seen at channel length of 0.22 μm , while at $L = 0.12 \mu\text{m}$ drift velocities up to 35% larger than the long channel value are measured.

I. INTRODUCTION

AS MOS transistor dimensions shrink to deep-submicrometer regime, nonlocal effects are expected to become more prominent. Perhaps the most important of these nonlocal effects is velocity overshoot, which can improve current drive and transconductance. Several authors have provided theoretical models (see [1], [2] and references therein). Recently, measurement of very high transconductance in 0.1- μm MOSFET's was attributed to velocity overshoot [3]. This attribution was made by comparing the measured transconductance with Monte Carlo simulation of the reported device [4]. Here we report observation of velocity overshoot, using a special test structure.

II. DEVICE STRUCTURE

As in our previous work of measuring saturation velocity [5], we employ back-channel conduction in silicon-on-insulator (SOI) MOSFET's. The SOI devices used in the study are built on SIMOX wafers. A full description of process integration is given in [6]. Here we provide only the key device parameters. As shown in Fig. 1, front-gate oxide thickness T_{fg} , silicon film thickness T_{si} , and buried oxide thickness T_{bg} are 18, 130, and 400 nm, respectively. The doping concentration is approximately $6-8 \times 10^{16} \text{ cm}^{-3}$. In the normal mode of operation of these devices, the inversion layer is formed at the front Si/SiO₂ interface. However, it is possible to form the inversion layer at the buried oxide / silicon interface by applying a very large back-gate voltage V_{bg} . To eliminate conduction by the front channel, negative front-gate voltage is applied to accumulate the front Si/SiO₂ interface. This unusual structure and bias condition provide a unique opportunity for observing velocity overshoot as follows. For short-

channel devices (e.g., 0.5 μm), only a small drain voltage (e.g., 1 V) is required to achieve a high tangential field. Since the drain voltage V_d is much smaller than back-gate voltage V_{bg} (e.g., 70 V), the inversion charge density is essentially uniform in the channel between source and drain. Thus the tangential field is uniform. This is to be contrasted with a regular thin-oxide MOSFET where the tangential field is nonuniform and increases significantly from source to drain.

The idea of utilizing very thick gate oxides to obtain uniform inversion layers was first tried in bulk MOSFET's by Fang and Fowler [7]. They used this technique to measure electron saturation velocity in inversion layers with good accuracy. However, if one employs a submicrometer bulk MOSFET with very thick gate oxide, the device will suffer from punchthrough. In the SOI MOSFET punchthrough is effectively suppressed due to the presence of thin silicon film.

III. RESULTS AND DISCUSSION

NMOSFET's with $W = 9.5 \mu\text{m}$ and channel lengths from 0.6 to 0.12 μm were used. Front-gate voltage was set to -4 V to accumulate the front interface, while the back-gate threshold voltage was about 11 V. Since V_{bg} was in the range of 60–100 V and V_d was kept below 1.5 V, the inversion charge was essentially uniform, allowing us to write $I = C_{bg}W(V_{bg} - V_t)v$, where C_{bg} is the buried oxide capacitance, V_t is the back gate threshold voltage, W is the channel width, and v is the electron drift velocity. Since v is the only unknown in this relation, it can be determined from the measured current. The tangential field is given by $E_y = (V_d - IR_{sd})/L$, where R_{sd} (series resistance) is 50–60 Ω for our devices.

Fig. 2 shows electron drift velocity versus tangential field for a 0.47- μm device. Very good agreement with Thornber's equation [8] is achieved for the usual choice of $\beta = 2$:

$$V(E_y) = \mu_o E_y \left(1 + \left(\frac{\mu_o E_y}{v_{\text{sat}}} \right)^\beta \right)^{-1/\beta}$$

As seen in this figure, the low field mobility at $V_{bg} = 50 \text{ V}$ is $480 \text{ cm}^2/\text{V} \cdot \text{s}$ and decreases to $390 \text{ cm}^2/\text{V} \cdot \text{s}$ at $V_{bg} = 90 \text{ V}$, as expected. Not surprisingly, velocity tends to saturate at tangential fields above $3 \times 10^4 \text{ V/cm}$, and it does not show strong dependence on the vertical field.

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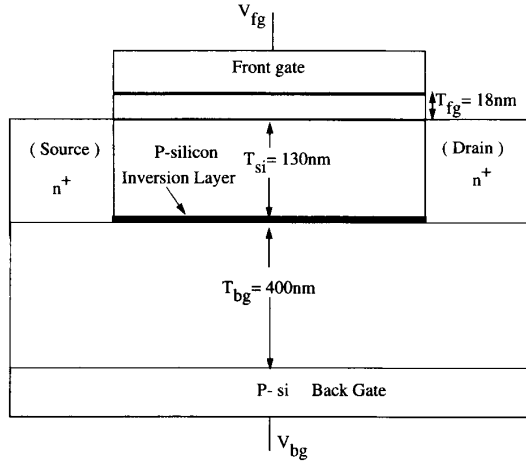


Fig. 1. Schematic cross section of an SOI MOSFET. By applying a large positive voltage to the back gate, the inversion layer is formed at the back Si/SiO₂ interface.

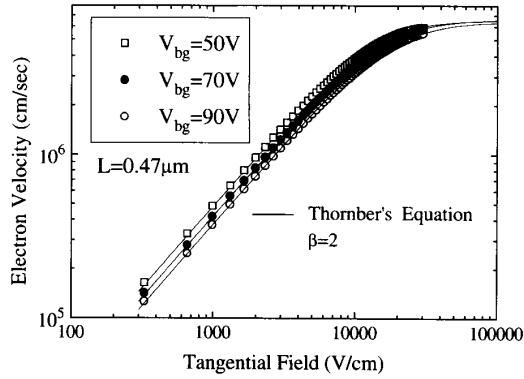


Fig. 2. Measured electron drift velocity versus tangential field for a device with $L = 0.47 \mu\text{m}$. Vertical field is used as a parameter.

Fig. 3 shows the results of similar measurements on devices with different channel lengths. $v(E_y)$ for channel lengths in the range of $0.6\text{--}0.35 \mu\text{m}$ nearly overlap, but for shorter channel lengths the high field velocity starts to increase with decreasing channel length. Clearly for $L < 0.25 \mu\text{m}$, the drift velocity exceeds the saturation velocity of long-channel structures. For example, at $L = 0.12 \mu\text{m}$ drift velocities up to 35% larger than the saturation velocity are observed. It should be noted that the concept of uniform charge, electric field, and drift velocity that we used to derive the velocity/field relationship is only valid for long-channel devices (i.e., $L > 0.32 \mu\text{m}$). For very short devices (where overshoot is not negligible), the velocity is not constant in the channel, and the values reported here should be treated as “average” drift velocities.

Fig. 4 shows the average drift velocity as a function of channel length, with the tangential field as a parameter. For $L > 0.25 \mu\text{m}$ (e.g., $L = 0.32 \mu\text{m}$), as tangential field

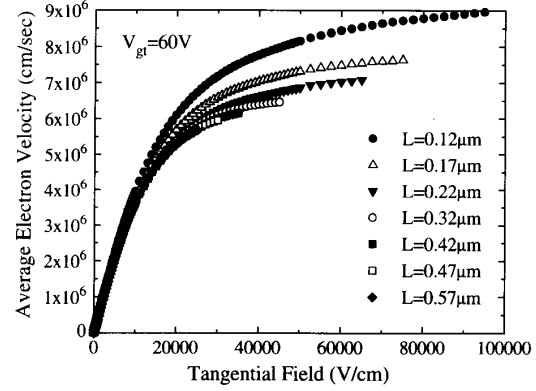


Fig. 3. Measured electron drift velocity versus applied tangential field. Device channel length is used as a parameter. $V_{gt} = V_{bg} - V_t = 60 \text{ V}$.

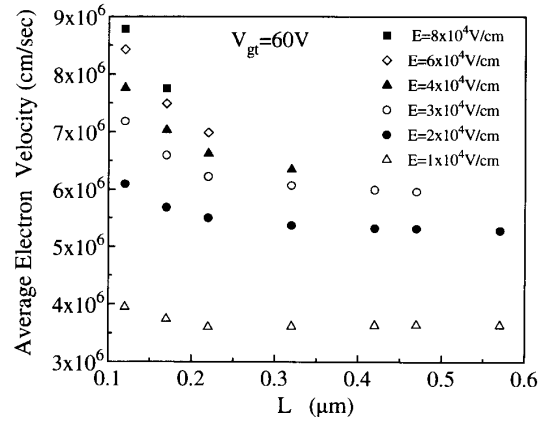


Fig. 4. Average electron drift velocity versus channel length, with tangential field used as a parameter.

increases the drift velocity increases but tends to saturate for larger fields. This is to be contrasted with the $L = 0.12\text{-}\mu\text{m}$ device, which shows no clear velocity saturation even at $E_y = 8 \times 10^4 \text{ V/cm}$. Moreover, for relatively moderate fields (e.g., $1 \times 10^4 \text{ V/cm}$), the measured velocities for all different channel lengths are about the same and no significant overshoot is observed. This is obviously not the case for larger fields.

One complicating factor in the above measurements is that for very short channel lengths, the threshold voltage becomes dependent on the drain voltage. Fig. 5 shows $I_d\text{--}V_g$ characteristics of the $0.12\text{-}\mu\text{m}$ device, which represents the worst case of V_t reduction. We took into account the V_d dependence of threshold voltage, by measuring current shifts at different drain voltages.

IV. CONCLUSION

Novel SOI structures are utilized to study the phenomenon of velocity overshoot. Velocity overshoot is observed at room temperature for channel lengths as long as $0.22 \mu\text{m}$. At $0.12 \mu\text{m}$, drift velocities up to 35% larger than the saturation velocity are measured.

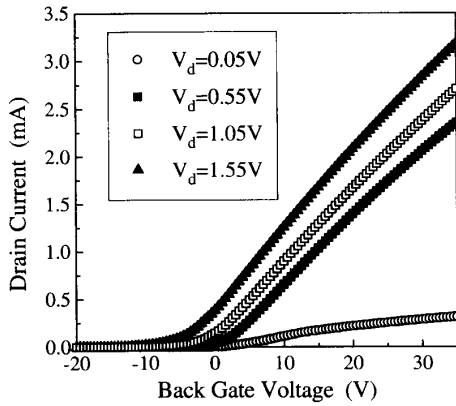


Fig. 5. Drain current of the $L = 0.12\text{-}\mu\text{m}$ device plotted as a function of back-gate voltage. Drain voltage is used as a parameter.

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